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The most plausible explanation of the cyclical period changes in close binaries: the case of the RS CVn-type binary WW Dra

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ABSTRACT

Cyclical period changes are a fairly common phenomenon in close binary systems and are usually explained as due to **either** the magnetic activity of one or both components (e.g., Applegate 1992) or to the light-travel time effect(LTTE) of a third body. We searched the orbital period changes in 182 EA-type (including the 101 Algol systems used by Hall (1989)), 43 EB-type and 53 EW-type binaries with known both the mass ratio and the spectral type of their secondary components. We reproduced and improved the same diagram as Hall's (1989) according to the new collected data. Our plots do not support the conclusion derived by Hall (1989) that all cases of cyclical period changes are restricted to binaries having the secondary component with spectral types later than F5. The presence of period changes also among stars with secondary component of early type indicates that the magnetic activity is one cause, but not the only one, for the period variation. It is discovered that cyclic period changes, likely due to the presence of a third body are more frequent in EW-type binaries among close binaries. Therefore, the most plausible explanation of the cyclical period changes is the LTTE via the presence of a third body. By using the century-long historical record of the times of light minimum, we analyzed the cyclical period change in the Algol binary WW Dra. It is found that the orbital period of the binary shows a $\sim$ 112.2**yr** cyclic variation with an amplitude of $\sim$ 0.1977**days**. The cyclic oscillation can be attributed to the LTTE via a third body with a mass no less than $6.43 M_{\odot}$. However, no spectral lines of the third body were discovered indicating that it may be a candidate black hole. The third body is orbiting the binary at a distance shorter than 14.4 AU and it may play an important role in the evolution of this system.

Key words: binaries : close – binaries : eclipsing – stars: individual: WW Dra– stars: late-type.

1 INTRODUCTION

Orbital period changes of stellar eclipsing binary systems can be investigated by analyzing the $(O - C)$ diagram showing the difference between the observed epochs of light minimum and those computed with a given ephemeris. A periodic pattern in an $O - C$ curve is a fairly common phenomenon in **Algols**, W Ursae Majoris binaries, and RS Canum Venaticorum and the cataclysmic variables (Hall 1989; Hall & Kreiner 1980; Hobart et al. 1994; Warner 1988). Similar patterns of the $O - C$ diagram for several classes of close binaries suggest a common underlying mechanism (Zavala et al. 2002), such as mass loss, apsidal motion, magnetic activity, and **presence** of a third body. Zavala et al. (2002) thought that apsidal motion and mass loss are unlikely mechanisms. Therefore, at present, cyclical period changes can usually be explained as due to **either** the magnetic activity of one or both components (e.g., Applegate 1992) or to the light-travel time effect(LTTE) via the presence of a third body.

The hypothesis that cyclical period changes are caused by the presence of a third body has been discussed by several investigators (Frieboes-Conde & Herczeg 1973; Chambliss 1992a; Borkovits & Hegedüs 1996). In this hypothesis, the motion of the binary around the center of mass of the system causes a periodic change in the observed period due to a light-travel time effect(LTTE), thereby creating a periodic pattern in $O - C$ curve. Afterwards, Hall found a striking correlation between the spectral type of the low-mass secondary component and the presence of a cyclical period change in his study (Hall 1989) on 101 Algols. From his plot, he noted that all cases of cyclical period changes are restricted to systems with spectral types of the secondaries later

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than F5. Based on this result, Applegate (1992) and Lanza et al. (1998) developed a theory to explain the periodic pattern in $O-C$ curves of these systems. In this **theory**, a certain amount of angular momentum is periodically exchanged between the inner and the outer parts of the convection zone, and therefore the rotational oblateness of the star and hence the orbital period changes while the system's component goes through its activity cycles. However, the period changes of those Algols used by Hall (1989) were mainly derived from visual and photographic observations. **This theory was frequently used to interpret the orbital period modulation of close binaries containing at least one cool component (e.g., Hall 1991; Qian et al. 1999; Qian et al. 2000)**. As new and more accurate observational material has accumulated since then, **in** the present work, we will reproduce and improve the same diagram as Hall's (1989) of EA, EB and EW-type binaries based on the new collected data. We will check Hall's plot and discuss the cause of cyclical period changes. Meanwhile, we will analyze the cyclical period change of the RS CVn-type binary WW Dra derived from the century-long historical record of the times of light minimum and discuss its plausible cause.

2 THE MOST PLAUSIBLE EXPLANATION OF THE CYCLICAL PERIOD CHANGES

As discussed above, at present, the magnetic activity of one or both components (e.g., Applegate 1992) or the light-travel time effect(LTTE) via the presence of a third body are usually invoked to explain **the cyclical** period changes of close binaries. Hall (1989) searched the orbital period changes of 101 Algol-type binaries in Giuricin et al. (1983). The samples of our study are made by the stars listed in Kreiner et al. (2001), the 101 Algol systems in Giuricin et al. (1983), and the Algol-type binaries listed in İbanoğlu et al. (2006). As selection criterion we considered stars that either show cyclical period changes or have secondary component of late spectral type. Finally, 182 EA-type (including the 101 Algol systems used by Hall (1989)), 43 EB-type, and 53 EW-type binaries were collected for this study.

In this paper, the data of EA, EB, and EW-type binaries are presented in Tables 1 - 3, respectively. In Table 1, Column (1) and (7) give the systems we selected; (2) and (8) the secondary component's spectral type; (3) and (9) the mass ratio; (4) and (10) the form of the period change; (5) and (11) the geometrical structure of the binary : semidetached binaries(SD) or detached binaries(D), and (6) and (12) the reference for the $O-C$ information.

In Table 2 and 3, Column (1) gives the systems we selected; (2) the secondary component's spectral type; (3) the mass ratio; (4) the form of the period change and (5) the reference for the $O-C$ information. The secondary component's spectral type (Sp_2) and the mass ratio (q) are up to date values taken from one of these references: Kreiner et al. (2001), Giuricin et al. (1983), İbanoğlu et al. (2006), the reference given in corresponding table, and VizieR database [1]. Therefore, some of the secondary component's spectral types in Table 1 differ from those in Giuricin et al. (1983). Moreover, in the process of investigation, we reclassified several systems as EB type or detached binaries with respect to Giuricin et al. (1983) according to the mentioned more recent bibliography.

The plots of mass ratio(q) vs. secondary component's spectral type (Sp_2) for EA, EB, and EW-type binaries are displayed in Figs. 1 - 3, respectively. The form of the period change follows the convention adopted by Hall (1989). A horizontal line (-) indicates no period change, a forward slash (/) indicates a period increase only, a back slash (\ ) indicates a period decrease only, a cross ($\times$) indicates both increase and decrease of the period, and a filled circle ($\bullet$) is used for systems for which we have inadequate data for judgement. In Fig. 1, the magenta symbols are used for the semidetached Algol-type binaries and the black ones are for detached Algol-type binaries. It is clear from Fig. 1 that our plots do not support the conclusion derived by Hall (1989) that all cases of cyclical period changes are restricted to binaries with secondary component with spectral type later than F5. There are cases among both semidetached and detached Algols in which the spectral type of the secondary component is earlier than F5, such as RW Cap (Erdem et al. 2007), TX Her (Ak et al. 2004), and it is expected that the number of these systems will grow rapidly as more new observational data will be derived. The presence of period changes also among systems with low-mass component of early-type stars **rules the magnetic activity out as unique cause** for the period variation. Among binaries with late-type component the orbital period variation can be due to either magnetic activity or LTTE. Whereas, among binaries with early-type components the LTTE is the more likely cause. Moreover, the validity of the Applegate mechanism has recently come into question (Lanza 2005, 2006). Lanza suggested that the Applegate mechanism should be rejected because it can not explain the orbital period modulations of classical RS CVn close binaries (Lanza 2005). Afterwards he also found that the mechanism is inadequate to explain the cyclical period changes of all close binaries with a late-type secondary (Lanza 2006). Again, the Applegate mechanism predicted that there is a connection between the luminosity variation and the variation of period. However, to date, no reliable connections were found in the literature. Therefore, the most plausible explanation of the cyclical period changes is the LTTE via the presence of a third body. We found that 48.9 % of EA, 44.2 % of EB and 64.2 % of EW-type binaries have cyclical orbital period variation. If we assume that such variations are related to the presence of a third body through the LTTE, then we find that EW stars have the highest probability to belong to multiple systems. These results are in agreement with the findings of Chambliss (1992b). The detailed statistical numbers of cyclical period changes in close binary systems are displayed in Table 4.

In the following sections,we present our investigation on the cyclical period change in the RS CVn-type binary WW Dra and discuss about its causes as the presence of a black hole companion.

3 NEW CCD PHOTOMETRIC OBSERVATIONS FOR WW DRA

WW Dra (= HD 150708 = HIP 81519 = BD +60°1691, $V_{max} = 8.3\,mag$) was discovered to be an eclipsing binary by Harwood (1916). **It is a RS CVn-type eclipsing binary with G2+K0 spectral type (Joy 1941).** Studies based on photographic and photoelectric observations were carried out by Plaut (1940), Mezzetti et al. (1979), Mardirossian et al. (1980) and Tunca et al. (1981). Some of them also calculated the orbital and physical elements of WW Dra, and the binary was confirmed to be a detached system composed of two sub-giant stars. The period variation of this binary was studied by Albayrak et al. (1999) who derived the parameters of the light time orbit. However, as more new observational data have been derived since then, we will display different results of orbital period change **of** WW Dra.

[1] http://vizier.u-strasbg.fr/, operated at CDS, Strasbourg, France.

Table 1. Period changes of semidetached and detached Algol-type binaries.

Star	Sp$_2$	q	Type of ΔP	Geo.Str	Ref.	Star	Sp$_2$	q	Type of ΔP	Geo.Str	Ref.
TT And	[G7IV]	0.29	$\times$	SD	(1)	RS Vul	G0III-IV	0.310	-	SD	(35)
TW And	K0-K1	0.21	$\times$	SD	(2)	BE Vul	K2-K3	0.40	\	SD	(17)
XZ And	G5IV	0.4	$\times$	SD	(3)	V78ωCen	K2-K3	0.25	$\bullet$	SD	(36)
KO Aql	(F8IV)	0.223	/	SD	(4)	TY Del	G0IV	0.03	$\times$	SD	(6, 10^+)
V342 Aql	[K0IV]	0.28	$\times$	SD	(1)	VX Lac	K4IV	0.32	$\times$	SD	(6, 10^+)
V346 Aql	G	0.3	\	SD	(5)	RV Per	[G74]	0.29	$\times$	SD	(6)
RY Aqr	G8?	0.230	$\times$	SD	(6)	BO Vul	G0IV	0.44	$\times$	SD	(6, 10^+)
SS Cam	F5V	0.954	$\times$	SD	(7)	IV Cas	G1V	0.5	$\times$	SD	(6, 10^+)
RW Cap	A4	0.450	$\times$	SD	(1)	BF CMi	[K0IV]	0.3	$\times$	SD	(6)
QZ Car	B0g	0.60	$\times$	SD	(8)	TY Cap	[G3.5IV]	0.4	$\times$	SD	(6)
AB Cas	K0	0.22	/	SD	(5)	DK Cep	[G4IV]	0.560	$\times$	SD	(6)
BZ Cas	[G1.5IV]	0.32	$\times$	SD	(1)	SS Cet	[KOIV]	0.25	$\times$	SD	(6)
RZ Cas	G5IV	0.351	$\times$	SD	(9)	RR Dra	[G8IV]	0.28	$\times$	SD	(6)
TV Cas	G2	0.470	$\times$	SD	(10)	UZ Sge	[G0IV]	0.14	$\times$	SD	(6)
TW Cas	K4-K5	0.41	\	SD	(5, 11)	EW Lyr	[K3IV]	0.300	$\times$	SD	(6)
U Cep	G8III-IV	0.550	$\times$	SD	(12)	YY Gem	M1V	1.006	$\times$	D	(37)
XX Cep	(G4IV)	0.150	$\times$	SD	(10)	RX Her	A0V	0.847	-	D	(5)
XY Cep	(G4IV)	0.250	\	SD	(13)	TX Her	F2V	0.895	$\times$	D	(38)
GT Cep	B9.5g	0.34	$\bullet$	SD	(5)	VZ Hya	F6V	0.911	$\bullet$	D	(5)
R CMa	G8IV-V	0.170	$\times$	SD	(6)	HS Hya	F5V	0.971	$\bullet$	D	(5)
TZ CrA	K2-K3	0.3	$\bullet$	SD	(5)	CM Lac	F0V	0.782	-	D	(5)
U CrB	F8III-IV	0.289	$\times$	SD	(3)	UV Leo	G2V	0.917	$\times$	D	(5)
RW CrB	K3	0.220	\	SD	(14)	FL Lyr	G8V	0.787	-	D	(5)
SW Cyg	K3	0.190	$\times$	SD	(5)	UX Men	F8V	0.968	$\bullet$	D	(5)
UW Cyg	K4IV	0.28	$\times$	SD	(15)	CD Tau	F7V	0.949	$\bullet$	D	(5)
WW Cyg	(G9)	0.310	$\times$	SD	(16)	DM Vir	F7V	0.991	$\bullet$	D	(5)
ZZ Cyg	K6	0.52	\	SD	(5)	RS Ari	G5	0.360	$\bullet$	D	(5)
KU Cyg	K5eIII	0.125	$\bullet$	SD	(5)	WW Aur	A7Vm	0.905	-	D	(5)
MR Cyg	B8	0.56	$\times$	SD	(3)	SS Boo	KIIV	0.988	$\bullet$	D	(5)
TT Del	G7IV	0.290	$\times$	SD	(17)	SV Cam	K4V	0.670	$\times$	D	(5)
W Del	K1-K2	0.18	$\times$	SD	(3)	RS CVn	F4V-IV	0.958	\	D	(5)
Z Dra	K3-K4	0.23	$\times$	SD	(12)	FZ CMa	B3IV-V	0.880	$\times$	D	(6, 53)
TW Dra	K0III	0.470	$\times$	SD	(12)	RW UMa	K1IV	0.951	$\bullet$	D	(5)
AI Dra	GV-IV	0.429	$\times$	SD	(18)	BH Vir	G2V	0.950	$\bullet$	D	(5)
S Equ	K0-K1	0.131	$\times$	SD	(12)	HW Vir	M	0.2931	$\times$	D	(39, 40)
AS Eri	G6IV	0.110	$\bullet$	SD	(5)	XX Cas	B6n	0.36	$\bullet$	D	(5)
TZ Eri	K0-1III	0.19	$\times$	SD	(6)	AQ Cas	B9	0.28	$\bullet$	D	(5)
WX Eri	F6V:	0.29	$\bullet$	SD	(5)	GG Cas	K0III	0.78	$\bullet$	D	(5)
RW Gem	F5Ib-I	0.290	-	SD	(5)	MN Cas	A0V	0.960	$\bullet$	D	(5)
AF Gem	G0III-IV	0.342	\	SD	(5)	ZZ Cep	F0V	0.460	$\bullet$	D	(5)
X Gru	K4-K5	0.27	/	SD	(19)	UX Com	G2V	0.855	$\bullet$	D	(5)
μ Her	B6	0.36	-	SD	(5)	RT CrB	G0	0.991	$\times$	D	(41)
SZ Her	G8-G9	0.4	$\times$	SD	(12, 20)	V909 Cyg	A2	0.850	$\bullet$	D	(5)
UX Her	K?	0.210	$\times$	SD	(12, 21)	WW Dra	K0IV	0.985	$\times$	D	(42)
AD Her	K2	0.350	-	SD	(22)	RZ Eri	K0	0.963	$\bullet$	D	(5)
V338 Her	K6	0.16	$\times$	SD	(12)	V819 Her	F8V	0.704	$\times$	D	(43)
RX Hya	M5	0.24	$\times$	SD	(15)	AW Her	K2	0.906	$\bullet$	D	(5)
TT Hya	G6III	0.224	$\bullet$	SD	(5)	DQ Her	M3V	0.66	$\times$	D	(44, 45^*)
TW Lac	[K0IV]	0.26	$\times$	SD	(1)	MM Her	G2V	0.944	$\bullet$	D	(5)
RW Leo	F4	0.24	$\times$	SD	(2)	AR Lac	K0IV	0.897	$\times$	D	(46)
Y Leo	K5	0.3	$\times$	SD	(12)	AO Mon	B5	0.950	$\bullet$	D	(5)
RS Lep	M0	0.3	$\times$	SD	(5)	V635 Mon	A2	0.420	$\bullet$	D	(5)
δ Lib	K2IV	0.345	/	SD	(21, 23)	SZ Psc	F5-8V	0.766	$\bullet$	D	(5)
T Lmi	G5III	0.130	$\times$	SD	(6)	TY Pyx	G5IV	0.987	$\bullet$	D	(5)
TT Lyr	K0	0.27	-	SD	(5)	AC Cnc	K2	0.77	$\times$	D	(47)
FW Mon	F2	0.36	$\bullet$	SD	(5)	PW Her	K0IV	0.768	$\times$	D	(41)
TU Mon	F3	0.210	-	SD	(5)	EU Hya	G0	0.630	$\times$	D	(48)
AR Mon	K2III	0.30	$\bullet$	SD	(5)	QY Aql	K5	0.33	$\bullet$	D	(5)
RV Oph	K0	0.10	-	SD	(12)	V805 Aql	(A9)	0.773	-	D	(5)
UU Oph	G8-G9	0.29	$\bullet$	SD	(24)	AR Aur	B9V	0.925	$\times$	D	(5)
AQ Peg	G5	0.21	$\times$	SD	(12)	β Aur	A1IV	0.969	$\bullet$	D	(5)
AT Peg	K6	0.484	$\times$	SD	(3)	HS Aur	K0V	0.977	$\bullet$	D	(5)
DI Peg	K0	0.3	$\times$	SD	(25)	IM Aur	A5V:	0.431	$\times$	D	(49)
RY Per	F7:2-3	0.271	-	SD	(12)	SU Boo	K2	0.11	$\bullet$	D	(5)
RT Per	K2-K3	0.24	$\times$	SD	(12)	Y Cam	K0	0.240	$\times$	D	(10)
ST Per	K1-2IV	0.150	$\times$	SD	(3)	SZ Cam	B0.5V	0.25	$\times$	D	(50)
DM Per	A5III	0.284	$\times$	SD	(26)	YZ Cas	F2V	0.584	$\bullet$	D	(5)
β Per	G8III	0.217	$\times$	SD	(27)	SZ Cen	A7V	1.018	$\bullet$	D	(5)
Y Psc	K0IV	0.250	$\times$	SD	(5, 12)	WX Cep	A2V	1.090	$\bullet$	D	(5)
XZ Pup	(K2IV)	0.400	$\bullet$	SD	(5)	EI Cep	F1V	1.054	-	D	(5)
RZ Sct	A2IV	0.216	$\bullet$	SD	(5)	RS Cep	G	0.145	/	D	(5)
EG Ser	A	0.905	$\bullet$	SD	(5)	XY Cet	Am	0.926	$\bullet$	D	(5)
U Sge	G4III-IV	0.370	$\times$	SD	(28)	S Cnc	G8-9III-IV	0.090	-	D	(5)
RS Sgr	A2V	0.36	$\bullet$	SD	(5)	UZ Cyg	K1	0.07	-	D	(5)
XZ Sgr	G5IV-V	0.140	$\bullet$	SD	(5)	VW Cyg	G5	0.280	/	D	(5)
V505 Sgr	F7IV	0.520	$\times$	SD	(29)	BS Dra	F5V	1.000	-	D	(5)
AC Tau	[G]	0.683	$\times$	SD	(15)	CM Dra	M4V	0.873	$\bullet$	D	(5)
HU Tau	F5III-IV	0.256	-	SD	(30)	AL Gem	K4	0.10	/	D	(5)
RW Tau	K0V	0.19	$\times$	SD	(31)	RX Gem	K2?	0.254	$\times$	D	(51)
λ Tau	A4IV	0.263	-	SD	(5)	RY Gem	K0-3IV-V	0.193	\	D	(5)
X Tri	G3	0.51	$\times$	SD	(32)	AU Mon	F8-G0II-III	0.199	$\bullet$	D	(5)
V Tuc	(K2)	0.28	$\bullet$	SD	(5)	FS Mon	F4V	0.896	$\bullet$	D	(5)
TX UMa	F6IV	0.248	$\times$	SD	(12)	U Oph	B6V	0.925	$\times$	D	(52)
VV UMa	G6	0.21	$\times$	SD	(33)	WZ Oph	F8V	0.982	-	D	(5)
W Umi	(KOIV)	0.490	\	SD	(5)	DN Ori	G	0.07	$\bullet$	D	(5)
RT UMi	K6	0.3	$\times$	SD	(5)	AW Peg	F5IV	0.16	$\bullet$	D	(5)
S Vel	K5IIIe	0.120	$\bullet$	SD	(34)	BK Peg	F8V	1.117	$\bullet$	D	(5)
DL Vir	K0IV	0.570	$\bullet$	SD	(5)	EE Peg	F5V	0.619	$\bullet$	D	(5)
UW Vir	K3IV	0.23	$\times$	SD	(15)	RW Per	G0III	0.150	$\times$	D	(54)
AY Vul	K	0.24	$\times$	SD	(2)	ς Phe	B8V	0.651	$\times$	D	(43)
Z Vul	A2III	0.430	$\times$	SD	(5)	UV Psc	K3V	0.733	-	D	(5)

Note. $^+$ the reference for the Sp$_2$. * the reference for the mass ratio q

References: (1) Erdem et al. (2007); (2) Qian (2003a); (3)Borkovits & Hegedüs (1996); (4) Hayasaka (1979); (5) Kreiner et al. (2001); (6) Zasche (2005); (7) Qian et al. (2009a); (8) Mayer et al. (2001); (9) Narusawa et al. (1994); (10)Hoffman et al. (2006); (11) McCook (1971); (12) Kreiner (1971); (13)Kreiner & Tremko (1988); (14)Qian (2000a); (15)Qian (2000b); (16)Zavala et al. (2002); (17)Qian (2001a);(18)Değirmenci et al. (2000);(19)Schulz (1977); (20)Baldwin & Samolyk (1997); (21)Baldwin & Samolyk (1996); (22)Batten & Fletcher (1978); (23)Koch (1962); (24)Taylor (1981); (25)Lu (1992); (26)Hilditch et al. (1986); (27)Soderhjelm (1980); (28)Simon (1997); (29)Qian et al. (1998); (30)Parthasarathy & Sarma (1980); (31)Frieboes-Conde & Herczeg (1973); (32)Rovithis-Livaniou et al. (2000); (33)Simon (1996); (34)Sisteró (1971); (35)Kreiner & Ziolkowski (1978); (36)Sisteró et al. (1969); (37)Qian et al. (2009b); (38)Ak et al. (2004); (39)Qian et al. (2008a); (40)Lee et al. (2009); (41)Qian et al. (2003b); (42)This paper ; (43)Zasche et al. (2009); (44)Dai & Qian (2009); (45)Mukai et al. (2003); (46)Frasca & Lanza (2000); (47)Qian et al. (2007a); (48)Qian & Boonrucksar (2003c); (49)Mayer (1990); (50)Lorenz et al. (1998); (51)Qian et al. (2002); (52)Wolf et al. (2002); (53)mof et al. (1983); (54)Mayer (1984);

Table 2. Period changes of EB-type binaries.

Star	Sp_2	q	Type of ΔP	Ref.
AD And	A0V	1.000	×	(1)
V337 Aql	B1.5	0.6	\	(2)
SX Aur	B3V	0.57345	/	(3, 4*)
TT Aur	B4	0.668	×	(5)
BF Aur	B5V	1.048	•	(3, 6*)
HL Aur	G9V	0.722	×	(7)
IU Aur	B0.5V	0.672	×	(8)
LY Aur	B0.5III	0.62	•	(3, 9*)
YY CMi	F5	0.89	•	(3, 10*)
RX Cas	gG3	0.31	/	(3, 11*)
CC Cas	O8	0.415	•	(3, 12*)
CR Cas	B1V	0.769	•	(3, 13*)
ZZ Cas	[B9]	0.7	×	(14)
SV Cen	B6III	0.707	\	(3, 15*)
BH Cen	B3?	0.84	×	(16)
EG Cep	F2V	0.464	×	(17)
V701 Cen	A3IV-V	0.617	•	(18++)
V758 Cen	A9	0.387	•	(19++)
AH Cep	B0.5V	0.87	×	(20)
CQ Cep	O7	1.03	×	(21, 22*)
GK Cep	A0V	0.913	×	(3, 23*)
RV Crv	G0:	0.3	•	(3, 24*)
GO Cyg	A0n	0.428	/	(25)
KR Cyg	(F5)	2.04	•	(3, 26*)
V382 Cyg	O7.7V	0.551	×	(27)
V448 Cyg	B1Ib	0.555	•	(3)
V548 Cyg	F7	0.220	\	(3)
V729 Cyg	O8	0.282	•	(3, 28*)
RT Lac	G9IV	0.401	×	(29, 30*)
XX Leo	[F2]	0.82	×	(31)
β Lyr	A5	0.223	/	(3, 32*)
TU Mus	O9.5V	0.651	×	(27)
V Pup	B3	0.55	×	(33, 34*)
UZ Pup	A5	0.80	•	(3, 35*)
RT Scl	F0	0.443	\	(3, 36*)
RY Sct	B0	0.51	•	(3)
RU UMi	K	0.327	•	(3)
AC Vel	B7	1.00	•	(3, 37*)
BF Vir	G2	0.331	\	(3, 38*)
AS Ser	M0	0.3	×	(39)
GW Tau	[A8]	0.309	×	(40)
V701 Sco	B1-1.5	1	×	(16)
IR Cas	[F9IV]	0.2	×	(41)

Note. + the reference for the Sp_2. * the reference for the mass ratio q
References: (1) Liao & Qian (2009a); (2) Mayer (1987); (3) Kreiner et al. (2001); (4) Linnel et al. (1988); (5) Özdemir et al. (2001); (6) Kallrath & Strassmeier (2000); (7) Qian et al. (2006a); (8) Özdemir et al. (2003); (9) Drechsel et al. (1989); (10) Vivekananda et al. (1999); (11) Todorova (1993); (12) Hill et al. (1994); (13) Vitrichenko et al. (2007); (14) Liao & Qian (2009b); (15) Rucinski et al. (1992); (16) Qian et al. (2006b); (17) Zhu et al. (2009); (18) Milano et al. (1988); (19) Lipari & Sistero (1985); (20) Kim et al. (2005); (21) Borkovits & Hegedüs (1996); (22) Demircan et al. (1997); (23) Pribulla et al. (2009); (24) Giuricin et al. (1982); (25) Zabihinpoor et al. (1982); (26) Al-Naimiy et al. (1985); (27) Qian et al. (2007b); (28) Rauw et al. (1999); (29) Ibanoğlu et al. (2001); (30) Çakirli et al. (2003); (31) Zasche (2005); (32) Linnell et al. (1998); (33) Qian et al. (2008b); (34) Stickland et al. (1998); (35) Malasan et al. (1989); (36) Banks et al. (1990); (37) Johansen et al. (1997); (38) Russo & Sollazzo (1981); (39) Zhu et al. (2008); (40) Zhu & Qian (2006); (41) Zhu et al. (2004);

In order to analyze the period variations of WW Dra and investigate the physical properties of the third body, CCD observations were acquired on May 31, 2007 with the PI1024 TKB CCD photometric system attached to the 1.0-m reflector at the Yunnan Observatory. The V filter, close to the standard Johnson UBV system, was used. The effective field of view is about $6'.5 \times 6'.5$ at the Cassegrain focus and the size of each pixel is $0''.38$. The integration time is 60 s for each image. The coordinates of the nearby comparison star are RA=16:39:03.91, DEC=+60:42:02.6 (J2000.0). The PHOT task of IRAF, which measures the aperture magnitude for a list of stars, was used to reduce the observed images. By using our photometric data, **we provided the most recent determination of time of light minimum** - HJD 2454252.3029(±0.0018).

4 ORBITAL PERIOD VARIATION OF WW DRA

To investigate the physical properties of the third body in WW Dra, we search for cyclic orbital period changes. A total of 92 times of light minimum from the literature have been collected and compiled in the present paper. Most of times of light minimum were retrieved from compilation of Hall & Kreiner (1980). Times of light minimum are listed in the first and eighth column of Table 5. In our analysis, the value HJD2443221.544 obtained by Budding et al. (1977) was not used because its $(O - C)$ value shows large scatter when compared with the general trend formed by the other data points. In the second and ninth column the number (E) of orbits

Table 3. Period changes of EW-type binaries.

Star	Sp_2	q	Type of ΔP	Ref.
AB And	G5	0.560	×	(1, 2*, 3)
AK Her	F6V	0.277	×	(1, 3)
GZ And	G5V	0.514	×	(4, 5*)
S Ant	F4	0.33	/	(6, 7*)
V417 Aql	F9V	0.362	×	(8)
V803 Aql	K4	1.0	•	(6, 9*)
ZZ Boo	F2V	0.969	•	(6)
44i Boo	G1V	0.5	/	(6, 10*)
TX Cnc	F8V	0.455	×	(11)
RV CVn	G1	0.820	•	(6)
VW Cep	K0V	0.35	×	(12)
EM Cep	B1V	0.520	\	(6)
TW Cet	G5	0.530	\	(6, 13*)
AA Cet	F2V	0.240	•	(6)
RW Com	G2e	0.345	×	(13*, 14)
EK Com	G9V	0.304	•	(6, 13*)
V865 Cyg	G	0.446	•	(6, 13*)
BV Dra	F8V	0.402	×	(13*, 15)
BW Dra	G0V	0.280	×	(6, 13*)
YY Eri	G5	0.400	×	(13*, 6)
WY Hya	A6	0.850	•	(6)
SW Lac	G8p	0.797	×	(16, 13*, 6)
XY Leo	K0V	0.500	×	(6)
UV Lyn	G0V	0.367	•	(6, 13*)
V502 Oph	F9V	0.371	\	(6, 13*)
V566 Oph	F4V	0.241	×	(17)
V1010 Oph	(F6)	0.340	\	(6)
U Peg	F3	0.315	\	(6, 13*)
Y Sex	[F8.5]	0.449	×	(18)
V743 Sgr	G8	0.319	•	(6, 13*)
RZ Tau	A8V	0.540	×	(13*, 17)
W UMa	F8V	0.488	×	(6, 13*)
BM UMa	K	0.540	•	(6, 13*)
AH Vir	K0	0.420	/	(6, 13*)
ER Vul	G5V	0.957	•	(6)
BI CVn	[F9]	0.50	×	(19)
RZ Com	G9	0.430	×	(20)
VZ Lib	[F1.5]	0.460	×	(21)
AP Leo	[GO]	0.460	×	(22, 13*)
AD Cnc	[K0]	0.620	×	(23)
UX Eri	[F9]	0.440	×	(24, 13*)
EQ Tau	[G2]	0.442	×	(25, 13*)
AH Cnc	[F5]	0.5	×	(26)
V899 Her	[G]?	0.566	×	(27)
IK Per	[A2]	0.88	×	(28)
TV Mus	[F9.5]	0.25	×	(29)
FG Hya	[F8]	0.420	×	(30)
AO Cam	[F8]	0.6	×	(31)
AM Leo	[F7.5]	0.36	×	(31)
RR Cen	[F1.5]	0.18	×	(32)
EZ Hya	[F8]	0.350	×	(33)
GR Vir	[G1]	0.460	×	(34)
AG Vir	[F2]	0.160	×	(17)

Note. * the reference for the mass ratio q
References: (1) Borkovits & Hegedüs (1996); (2) Pych et al. (2004); (3)Hoffman et al. (2006); (4) Chambliss (1992a); (5) D'Angelo et al. (2006); (6) Kreiner et al. (2001); (7) Duerbeck & Rucinski (2007); (8) Qian et al. (2003b); (9) Liu et al. (2008); (10) Al-Naimiy et al. (1989); (11) Liu et al. (2007); (12) Pribulla et al. (2000); (13) Pribulla et al. (2003); (14) Qian (2002); (15) Yang et al. (2009); (16) Pribulla et al. (1999); (17) Qian (2001b); (18) He & Qian (2007); (19) Qian et al. (2008c); (20) He & Qian (2008); (21) Qian et al. (2008d); (22) Qian et al. (2007c); (23) Qian et al. (2007d); (24) Qian et al. (2007e); (25) Yuan & Qian (2007); (26) Qian et al. (2006c); (27) Qian et al. (2006d); (28) Zhu et al. (2005); (29) Qian et al. (2005a); (30) Qian & Yang (2005b); (31) Qian et al. (2005c); (32) Yang et al. (2005); (32) Yang et al. (2004); (34) Qian & Yang (2004);

Table 4. Statistical numbers of cyclical period changes in close binary systems.

	EA-type	EB-type	EW-type
(1)Total No.	106 (SD) + 76 (D)	43	53
(2)No. of ×	66 (SD) + 22 (D)	19	34
(3)Binaries with Sp_2 earlier than F5 in (2)	6 (SD) + 7 (D)	15	6
(4)ratio+	48.9%	44.2%	64.2%
(5)ratio*	14.8%	78.9%	17.6%

Note. + the ratio of binaries show cyclical period changes to the total number.
* the ratio of binaries not only show cyclical period changes but also have Sp_2 earlier than F5 to binaries show cyclical period changes.

elapsed from the initial epoch of primary minimum is listed. The $(O - C)_1$ values of all times of light minimum were computed with the linear ephemeris given by Kreiner et al. (2001),

$$Min.I = HJD\ 2427983.3236 + 4^d.6296328E, \tag{1}$$

They are listed in the third and tenth column of Table 5 and plotted vs. number of orbital periods in the upper panel of Fig. 4, where open circles refer to photographic or visual observations,

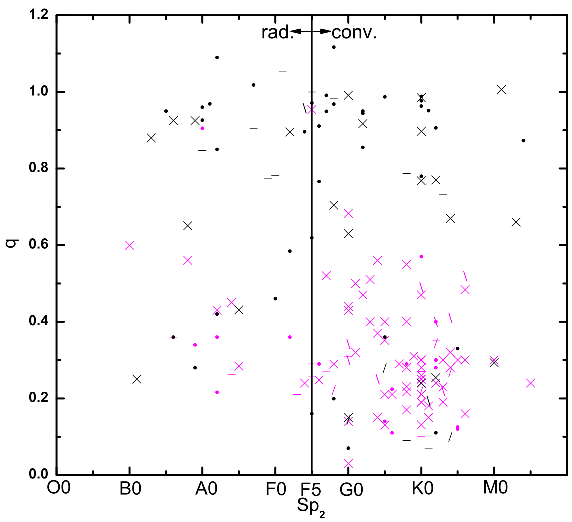

Figure 1. Plot of mass ratio(q) vs. secondary component's spectral type (Sp_2) for EA-type binaries listed in Table 1. A horizontal line (-) indicates no period change, a forward slash (/) indicates a period increase only, a back slash (\ ) indicates a period decrease only, a cross (×) indicates both increase and decrease of the period, and a filled circle (•) is used for systems for which have inadequate data for judgement. The magenta symbols are for the semidetached Algol-type binaries and the black ones are for detached Algol-type binaries.

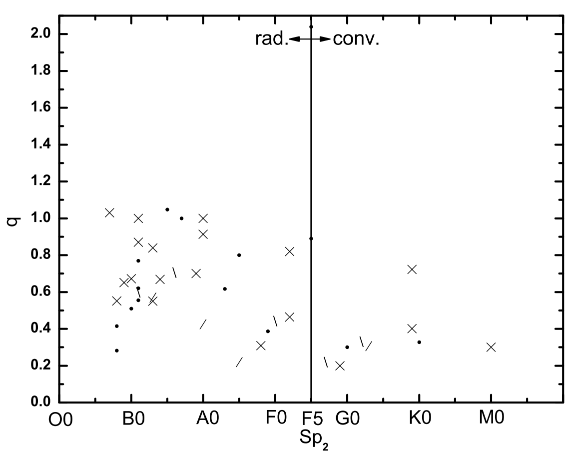

Figure 2. Plot of mass ratio(q) vs. secondary component's spectral type (Sp_2) for EB-type binaries listed in Table 2. The symbols are the same as in Figure 1.

filled circles to CCD or photoelectric ones. As shown in the upper panel of Fig. 4, the general $(O-C)_1$ trend can be described by a linear curve with superimposed a periodic fluctuation. Therefore, a sinusoidal term was added to a linear ephemeris to get a good fit to the $(O-C)_1$ curve (solid line in the upper panel of Fig. 4). **To** obtain a more accurate result, we focus the fit to only primary minima, though **secondary minima also** follow a similar trend. Weight

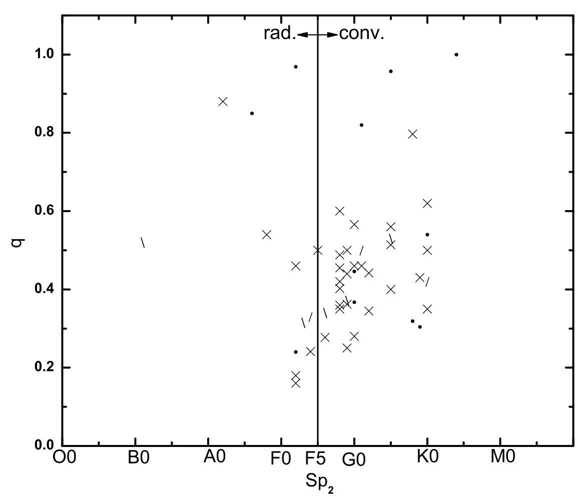

Figure 3. Plot of mass ratio(q) vs. secondary component's spectral type (Sp_2) for EW-type binaries listed in Table 3. The symbols are the same as in Figure 1.

0.1 and 0.8 were assigned to lower-precision observations (photographic or visual ones) and high-precision observations (CCD or photoelectric ones), respectively. A weighted least-squares solution yields the following equation,

$$
\begin{aligned}
Min.I = & \ 2427983.2814(\pm0.0188) + 4.^{d}6296389(\pm0.0000035)\times E \\
& +0.1977(\pm0.0096)\sin[0.^{\circ}0407\times E + 163.^{\circ}73(\pm0.^{\circ}05)].
\end{aligned} \quad (2)
$$

The sinusoidal term in Eq. (2) suggests a periodic variation with a period of about 112.2 **yr** and an amplitude of about $A = 0^{d}.1977$, which is more easily seen from the lower panel of Fig. 4, where the linear part of Eq. (2) was subtracted to the $(O-C)_1$ values. The good fit in Fig. 4 indicates no long-term steadily period increase or decrease. Therefore, we can exclude the presence of mass transfer, which is in accordance with the fact that WW Dra is a detached binary. The $(O-C)_2$ values are shown in the fourth and eleventh column of Table 5. The residuals of the fit with Eq. (2) are displayed in Fig. 5 and listed in the fifth and twelfth column of Table 5. **To** detect possible regular trends in the residuals plotted in Fig. 5, more high-precision times of light minimum are needed from future observations.

5 DISCUSSIONS AND CONCLUSIONS

In Section 4, we displayed the existence of a cyclical period change of WW Dra. This cyclical variation may be interpreted as due to **either** the magnetic activity of one or both components (Applegate 1992), or by the LTTE via the presence of a tertiary companion. With the following equation given by Rovithis-Livaniou et al. (2000),

$$\Delta P = \sqrt{2[1-\cos(2\pi P/P_3)]}\times A, \quad (3)$$

where P_3 is the period for the $(O-C)$ oscillation, the rate of the period variation is **found to be** $\Delta P/P = 5.29\times10^{-7}$. In order to

Table 5. ($O-C$) data for WW Draco.

JD.Hel. 2400000+	E	$(O-C)_1$	$(O-C)_2$	Residuals	Weight	Ref.	JD.Hel. 2400000+	E	$(O-C)_1$	$(O-C)_2$	Residuals	Weight	Ref.
15205.599	-27607	0.0619	0.27336	0.11874	0.1	(1)	39029.556	2386	-0.0715	-0.1756	0.01954	0.1	(1)
15501.809	-2696	-0.0246	0.18294	0.02288	0.1	(1)	39205.511	2424	-0.0425	-0.14893	0.04699	0.1	(1)
15774.848	-2637	-0.1339	0.07002	-0.09475	0.1	(1)	40844.335	2778	-0.1085	-0.23664	-0.04031	0.1	(5)
15955.582	-2598	0.0444	0.24593	0.07819	0.1	(1)	41043.396	2821	-0.1217	-0.25248	-0.05694	0.1	(6)
16390.638	-2504	-0.0851	0.11066	-0.06367	0.1	(1)	41154.547	2845	-0.0819	-0.21415	-0.01914	0.1	(7)
16418.486	-2498	-0.0148	0.18059	0.00585	0.1	(1)	41168.406	2848	-0.1118	-0.24424	-0.04929	0.1	(7)
16603.702	-2458	0.0158	0.20874	0.03144	0.1	(1)	41682.288	2959	-0.1191	-0.25834	-0.0666	0.1	(1)
16969.44	-2379	0.0128	0.2009	0.01897	0.1	(1)	41682.298	2959	-0.1091	-0.24834	-0.0566	0.1	(1)
17131.500	-2344	0.0357	0.22165	0.03786	0.1	(1)	41763.327	2976.5	-0.0986	-	-	not used	(8)
18867.661	-1969	0.0844	0.24735	0.05087	0.1	(1)	41830.474	2991	-0.0813	-0.22251	-0.0319	0.1	(1)
18955.495	-1950	-0.0446	0.11719	-0.07956	0.1	(1)	41904.533	3007	-0.0964	-0.23859	-0.04859	0.1	(9)
19191.586	-1899	-0.0649	0.09376	-0.10356	0.1	(1)	41904.536	3007	-0.0934	-0.23559	-0.04559	0.1	(9)
19890.777	-1748	0.0515	0.2009	0.00341	0.1	(1)	41918.503	3010	-0.0153	-0.15767	0.03219	0.8	(10)
22881.486	-1102	0.0177	0.12749	-0.04559	0.1	(1)	42617.379	3161	-0.2139	-0.36553	-0.18264	0.1	(11)
22895.458	-1099	0.1008	0.2104	0.03752	0.1	(1)	42904.6231	3223	-0.0070	-0.16243	0.01697	0.8	(12)
25247.247	-591	0.0364	0.11485	-0.01305	0.1	(1)	42955.456	3234	-0.1001	-0.25621	-0.07745	0.1	(1)
27284.275	-151	0.0260	0.07747	0.00209	0.1	(1)	43043.489	3253	-0.0301	-0.18737	-0.00977	0.1	(1)
27284.32	-151	0.0709	0.12237	0.04699	0.1	(2)	43057.404	3256	-0.0040	-0.16146	0.01595	0.1	(1)
27307.396	-146	-0.0012	0.04996	-0.02476	0.1	(1)	43071.241	3259	-0.0559	-0.21354	-0.03631	0.1	(1)
27321.296	-143	0.0098	0.06078	-0.01355	0.1	(3)	43161.535	3278.5	-0.0397	-	-	not used	(1)
27335.197	-140	0.0220	0.07279	-0.00115	0.1	(1)	43189.321	3284.5	-0.0315	-	-	not used	(1)
27344.447	-138	0.0127	0.06337	-0.01031	0.1	(4)	43212.490	3289.5	-0.0107	-	-	not used	(1)
27534.261	-97	0.0118	0.05995	-0.00835	0.1	(1)	43228.673	3293	-0.0314	-0.19113	-0.01606	0.1	(1)
27543.530	-95	0.0215	0.06953	0.00148	0.1	(1)	43307.414	3310	0.0058	-0.15497	0.01896	0.1	(1)
27557.409	-92	0.0116	0.05945	-0.0082	0.1	(1)	43330.558	3315	0.0017	-0.15937	0.01422	0.1	(1)
27557.418	-92	0.0206	0.06845	0.00079	0.1	(1)	43344.442	3318	-0.0032	-0.16446	0.00894	0.1	(1)
27645.3748	-73	0.0144	0.06108	-0.00405	0.1	(1)	43397.640	3329.5	-0.0460	-	-	not used	(1)
27654.6307	-71	0.0110	0.05756	-0.00731	0.1	(1)	43793.443	3415	-0.0766	-0.24381	-0.07735	0.1	(1)
27691.6670	-63	0.0103	0.05637	-0.00744	0.1	(1)	44168.521	3496	0.0011	-0.17107	-0.01102	0.1	(13)
27710.1918	-59	0.0165	0.06232	-0.00095	0.1	(1)	44446.3404	3556	0.0426	-0.13325	0.0217	0.8	(14)
27881.4789	-22	0.0072	0.05075	-0.00758	0.1	(1)	44446.3406	3556	0.0428	-0.13305	0.0219	0.8	(15)
27904.6277	-17	0.0079	0.05115	-0.00652	0.1	(1)	44446.3408	3556	0.0430	-0.13285	0.0221	0.8	(14)
27918.5176	-14	0.0089	0.05196	-0.0053	0.1	(1)	44874.373	3648.5	-0.1659	-	-	not used	(13)
27918.5197	-14	0.011	0.05406	-0.0032	0.1	(1)	45284.239	3737	-0.0224	-0.20935	-0.0714	0.1	(16)
27932.4068	-11	0.0092	0.05208	-0.00478	0.1	(1)	46175.376	3929.5	-0.0897	-	-	not used	(17)
27955.5536	-6	0.0078	0.05037	-0.00581	0.1	(1)	47631.6089	4244	0.1237	-0.0943	-0.01512	0.8	(18)
27983.3329	0	0.0093	0.05151	-0.00387	0.1	(1)	49534.4580	4655	0.1937	-0.04955	-0.02578	0.8	(19)
28020.3700	8	0.0093	0.05102	-0.00329	0.1	(1)	51636.31	5109	0.1924	-0.07869	-0.11832	0.1	(20)
28057.4074	16	0.0097	0.05092	-0.0023	0.1	(1)	52217.314	5234.5	0.1775	-	-	not used	(21)
28205.5510	48	0.0050	0.04426	-0.00462	0.1	(1)	52416.431	5277.5	0.2203	-	-	not used	(21)
28219.4445	51	0.0096	0.04868	0.0002	0.1	(1)	52576.270	5312	0.3370	0.05345	-0.01358	0.1	(22)
28307.4054	70	0.0075	0.04541	-0.00047	0.1	(1)	53516.1400	5515	0.3915	0.0955	0.00244	0.8	(23)
28404.6215	91	0.0013	0.03793	-0.00509	0.1	(1)	54136.5301	5649	0.4108	0.10658	-0.00261	0.8	(24)
33756.429	1247	-0.0467	-0.08096	0.03089	0.1	(1)	54210.598	5665	0.4046	0.0994	-0.01166	0.8	(24)
33756.463	1247	-0.0127	-0.04696	0.06489	0.1	(1)	54187.48083	5660	0.4356	0.13071	0.02022	0.8	(25*)
34455.498	1398	-0.0523	-0.09582	0.03284	0.1	(1)	54252.3029	5674	0.4428	0.13705	0.02493	0.8	(26)

Note. * the mean value of 3 times of light minimum

References: (1) Hall & Kreiner (1980); (2) Zverev (1933); (3)Kordylewski (1934); (4) Zverev (1937); (5) Diethelm & Locher (1970); (6) Diethelm & Locher (1971a); (7) Diethelm et al. (1971b); (8) BBSAG observers (1973a); (9) BBSAG observers (1973b); (10) Kizilirmak & Pohl (1974); (11) BBSAG observers (1975); (12) Mardirossian et al. (1980); (13) Isles (1984); (14) Pohl et al. (1982); (15) Tunca et al. (1981); (16) BBSAG observers (1983); (17) BBSAG observers (1985); (18) Isles (1992); (19) Blaettler (1994); (20) Hübscher et al. (2000); (21) Hübscher (2002); (22) Hübscher (2003); (23) Nagai (2006); (24) Hübscher (2007); (25) Brát et al. (2007); (26) The present author.

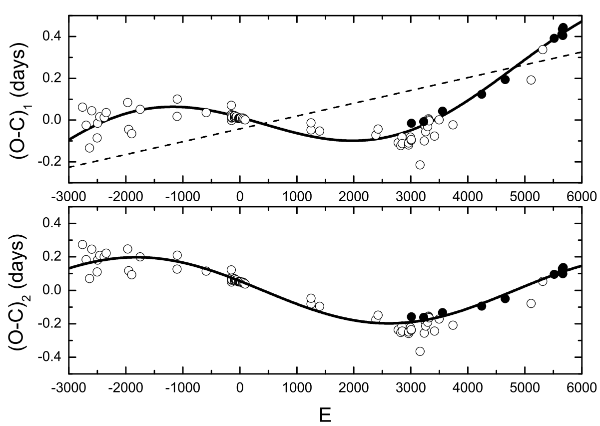

Figure 4. ($O-C$) diagram of WW Dra. The upper panel : $(O-C)_1$ diagram of WW Dra computed with Eq. (1). The open circles refer to photographic or visual observations, filled circles refer to CCD or photoelectric ones. The solid line refers to a combination of a linear ephemeris and a cyclical period variation, and the dashed line to a new linear ephemeris. The lower panel : $(O-C)_2$ curve of WW Dra as described by the sinusoidal term(solid line), after removing the linear term. The symbols are the same as in the upper panel.

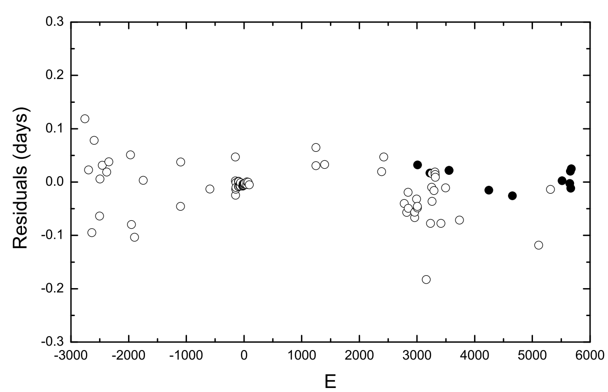

Figure 5. The residuals **from fit with Eq. (2)**. The symbols are the same as in the Fig. 4.

reproduce this cyclic change, the required variation of the quadruple momentum ΔQ can be calculated with the following equation (Lanza & Rodonò 2002),

$$\frac{\Delta P}{P} = -9\frac{\Delta Q}{Ma^2}, \tag{4}$$

where a is the separation between both components **that can** be determined with the Kepler's third law,

$$M_1 + M_2 = 0.0134\frac{a^3}{P^2}, \quad (5)$$

where $M_1 = 1.36M_\odot$ and $M_2 = 1.34M_\odot$ (Albayrak et al. 1999). Combining Eq. (4) and Eq. (5), we derived $\Delta Q_1 = 2.04 \times 10^{50}$ g cm^2 and $\Delta Q_2 = 2.01 \times 10^{50}$ g cm^2 for both components, respectively. Assuming conservation of the orbital angular momentum, **the total** ΔQ is on the order of $10^{51} - 10^{52}$ g cm^2 (Lanza & Rodonò 1999), **which indicates** the values of ΔQ_1 and ΔQ_2 for WW Dra are **not typical ones for the close binaries**, suggesting, that the mechanism of Applegate cannot interpret the cyclical period variation of WW Dra. Moreover, the period of 112.2 **yr** for the $(O - C)$ oscillation of WW Dra is too long in comparison with magnetic cycles in solar type single **stars** and close binaries (Maceroni et al. 1990; Bianchini 1990). Therefore, the cyclical period change is more plausibly interpreted as **due to** the presence of a third body.

The good sinusoidal fit shown in Fig. 4 suggests that the orbit of the third body is approximately circular, which is different from the result derived by Albayrak et al. (1999). Using $a_{12}\sin i' = A \times c$, where i' is the inclination of the orbit of the third component and c is the speed of light, $a_{12}\sin i'$ is computed to be 34.25(±1.66) AU. Then combining the following well-known equation,

$$f(m) = \frac{4\pi^2}{GP_3^2} \times (a\prime_{12} \sin i')^3, \quad (6)$$

with

$$f(m) = \frac{(M_3 \sin i_3')^3}{(M_1 + M_2 + M_3)^2} \quad (7)$$

the mass function of the third body is computed to be $f(m_3) = 3.19(\pm 0.47)\,M_\odot$. In the formula, M_1, M_2, and M_3 are the masses of the eclipsing pair and the third companion, respectively, G is the gravitational constant. According to the same parameters ($M_1 = 1.36M_\odot$ and $M_2 = 1.34M_\odot$) used by Albayrak et al. (1999), the lowest mass of the third body is calculated to be $M_3 = 6.43M_\odot$, and the third body is orbiting the binary at a distance shorter than 14.4 AU. When the third body is coplanar to the eclipsing binary : $i' = i = 81.^\circ 4$ (according to Albayrak et al. (1999)), its mass is $M_3 = 6.57M_\odot$. Using the formula given by Mayer (1990),

$$K_{RV} = \frac{2\pi}{P_3}\frac{a_{12}\sin i_3}{\sqrt{1 - e'^2}} \quad (8)$$

where K_{RV}, P_3, a_{12} are in kilometer per second, years and AU, respectively, and considering the simplest situation of $i_3 = 90^\circ$, the semi-amplitude of the system velocity accompanied by the light-time effect is approximately calculated to be 9.09 km s^{-1}, which is a little less than the value determined by Albayrak et al. (1999). According to Allen's tables (Drilling & Landolt 2000), the third companion is estimated to be a ~ B4 **star**. Therefore, it **could** be discovered by spectroscopic observation. However, no spectral lines of the third body were discovered up to now. It may be explained in two possible ways: (1) the star was observed in the past in a spectral range where the third body has no lines, or lines were present but the poor resolution of available spectra did not allow to detect them. Actually, it is difficult to find sufficient spectral lines to determine radial velocity of B stars because their rapid rotational velocity makes them too broad and weak to be accurately measured, or (2) the third body is a candidate black hole and it may play an important role in the evolution of this system. The situation resembles that of V Pup (Qian et al. 2008b). More observations are needed to check this hypothesis in the future. All these make WW Dra a very interesting system to study.

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